

An Exploration of Vehicle-Terrain Interaction in IR Synthetic Scenes

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ABSTRACT

IR synthetic scene fidelity improves with each leap ahead in computing capability. Military training, in particular, is reaping the benefits from each improvement in rendering fidelity and speed. However, in order for these synthetic scenes to be useful for signature virtual prototyping or laboratory observer trials, a particularly challenging aspect still needs to be addressed. Synthetic scenes need to have the ability to include robust physically reasonable active source prediction models for vehicles and to include physically reasonable interaction of vehicles with the terrain. Ground heating from exhaust, radiative heating and reflections between the vehicle and terrain, and tracks left on the terrain are just some examples of desired capabilities. For determining the performance of signature treatments, the effects must be more than artistic renderings of vehicle terrain interaction, but physically representative enough to make engineering determinations. This paper will explore the results of a first phase study to include MuSES targets in an existing IR synthetic scene program and the inclusion of exhaust impingement on the terrain.

Keywords: Signature, Infrared, visual signature, modeling, exhaust, FCS, materials, metrics, SMART, MATREX, virtual prototype

1.0 INTRODUCTION

IR synthetic scenes are used in a variety of military and commercial applications. The “fidelity” of these scenes has improved dramatically as computation power increases. The word *fidelity* here is used in the sense of physical representation, i.e. how “good” something looks subjectively. There is also the physics “fidelity” (or accuracy) of a simulation. This refers to the level to which a simulation includes such effects as validated first principles temperature prediction models; first principles predicted effects in nature--such as solar heating and reflections, atmospheric absorption, thermal shadowing; or more resource intense effects such as computational fluid dynamics in describing exhaust plumes and impingement effects or the use of the bi-directional reflection distribution function (BRDF). In simulations addressing ground vehicles, these effects have been addressed in a variety of degrees, but many simulations estimate these effects if they are addressed at all. The physics short cuts used in these simulations may in many applications be reasonable; however, in areas such as signature analysis of vehicles or identification friend or foe, they may not. There is an ongoing effort in the Army to create an IR/Vis synthetic scene that has the predictive physics fidelity needed to address the more demanding signature analysis arena as well as other related areas such as advanced sensor design.

1.1 The Ideal

Figure 1 shows a notional diagram of what the perfect simulation of this sort would include. Since we are dealing specifically with the topic of target-terrain interactions, the items in dashed lined boxes are the phenomena specific to this topic and the items in dot dashed lined boxes are items that are related. Clearly the ideal simulation would be quite an undertaking to do well. Therefore a group of like-minded organizations are coming together in a collaboration to develop such a simulation. This will give us the ability to leverage a diversity of expertise and multiple resources.

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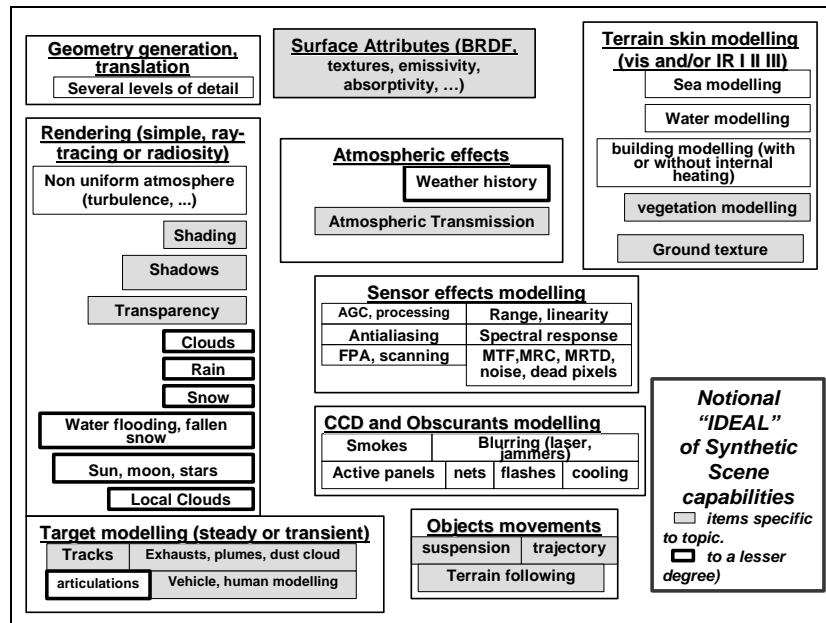


Figure 1 The Ideal

1.2 The Context of this effort

Figure 2 shows the context of the actual simulation development effort. The (as yet un-named) collaboration under which this effort is being conducted is almost worth studying as much as the topic. It is an informal cooperation between two formal Army Science and Technology Objectives (STOs), leveraging a cooperative agreements with industry (CRADA), an international exchange agreement between the US and UK, several Small Business Innovative Research Contracts (SBIR) and more.

The approach in developing this tool has been to break it apart into pieces that can be addressed by the different organizations with the appropriate expertise. For instance, one of the early projects addressed the first bottleneck—CAD migration. In figure 2, this is the area that falls between the “Inputs” and “Thermal Physics Preprocessing”. Current efforts have focused on easing the transition from commercial CAD programs such as Pro/E into analytical models—a process that traditionally has required much expertise and great tedium. Currently, it can take up to 80 hours to translate geometry from a CAD system, clean up the inevitable errors and prepare the converted geometry for analysis. Recent improvements in the process have reduced this time considerably. For example, now, Pro/E vehicle CAD models can be directly exported to the thermal model MuSES (Multi-Service Electro-optical Signature code) from within Pro/E Mechanic—which can then also import and display MuSES results (predicted temperatures).

1.3 The Target Thermal Model

One of the important assumptions in this process is that one has a legitimate target model in the first place that one wishes to integrate into a synthetic scene in some fashion. We mentioned MuSES above. Since MuSES is a robust predictive routine designed for rapid prototyping and is touted as the Army standard model for this purpose¹, it makes sense to leverage its performance. MuSES can also predict terrain temperatures as well—however; it is only a thermal model (not visual) and even given improved computer performance, it is also our belief that more research needs to be done in this area before one could rely on an extreme fidelity first principles synthetic scene over two kilometers square or more to create the ideal.

After the thermal modeling process, the target must be inserted into a synthetic scene, as illustrated in figure 2. Here is where the challenges arise. As described in the ideal, this rendering code must have task-appropriate atmospheric and

sensor effects applied and then generate images that can be assessed in a perception lab or analyzed against certain metrics--again, depending on the task. Once this is accomplished, changes can be made to the target, the sensor, or the type of experiment and then the process can be repeated.

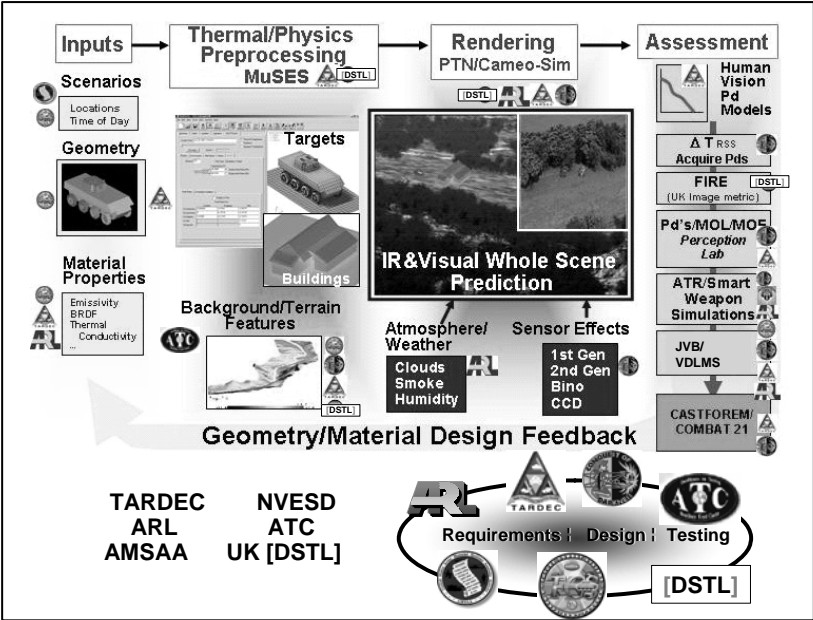


Figure 2 A Collaborative Effort

1.4 The Synthetic Scene

Our research led us to chose two synthetic scenes. One is the popular Paint-the-Night (PTN) IR scene simulation. PTN is based on Open-GL, is capable of real time performance, and has HLA and non-HLA versions. It is developed and used by NVESD primarily for advanced sensor performance modeling and it is now being distributed to other organizations. The second is Cameo-Sim (CS) developed in the UK under MoD (DSTL) sponsorship for signature simulation. CS is a broadband scene simulation software system that produces 32-bit imagery of natural static and moving (non-real time)² terrestrial scenes. Output imagery includes visible and IR in true and false colour (0.4 and 20.0 μm in any user-defined waveband). Each model brings certain strengths to the table and we believe that in using both in this study, we will strengthen the knowledge base, maintain a risk reduction strategy and benefit a wider range of users.

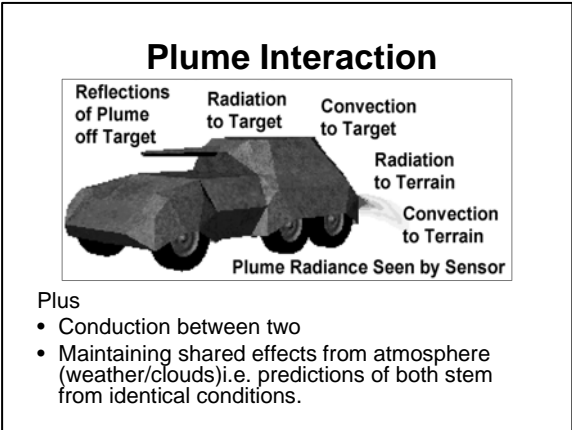


Figure 3 Defining the interaction

1.5 Defining the specific vehicle-terrain interactions

Outside the ideal, we have not yet identified the specific phenomena we plan to incorporate when we talk about vehicle-terrain interaction. Now we will define how we will work towards simulating the interaction between the two. The effects that we will address are shown in figure 3. Most are due to the exhaust of the vehicle that may impact the terrain through convection and radiation. Additional interactions occur where the vehicle touches the ground, such as conduction, track effects, and ground and dust displacement. Also, the interaction between the two models must be addressed from a software engineering perspective. In general, if two simulations such as these are being combined, we must make sure that they are synchronized in terms of weather and all other aspects. We have the choice of linking the two models together using HLA (High Level Architecture) or by imbedding the MuSES library into the synthetic scene program. Eventually we may exploit architecture within MATREX³ (Modeling Architecture for Technology and Research Experimentation--formerly VDLMS (Virtual Distributed Laboratory for Modeling and Simulation)) to combine the two. For now, we have chosen the "imbedded" method for the proof-of-principle stage.

2.0 THE APPROACH

We have identified the target model, the synthetic scene, and the notional steps that must be taken along with the effects we believe are important. Next, we need an implementation strategy to get us to our goal. We have taken the approach of developing this capability in stages with a proof-of-concept demonstration at each stage. During each stage, we will be able to take lessons learned and use them to develop an approach for integrating into other simulations or collection of simulations, such as MATREX³.

2.1 Allowing for the effects within the target model first

While developing the implementation strategy, the tasks were initially broken down into more detail. Figure 4 shows these tasks through the pipeline involved in achieving the goal: 1 predict the surface temperature, 2. link to CFD codes for the exhaust effects, 3. render the plume with appropriate radiation effects and 4. link to the synthetic scene.

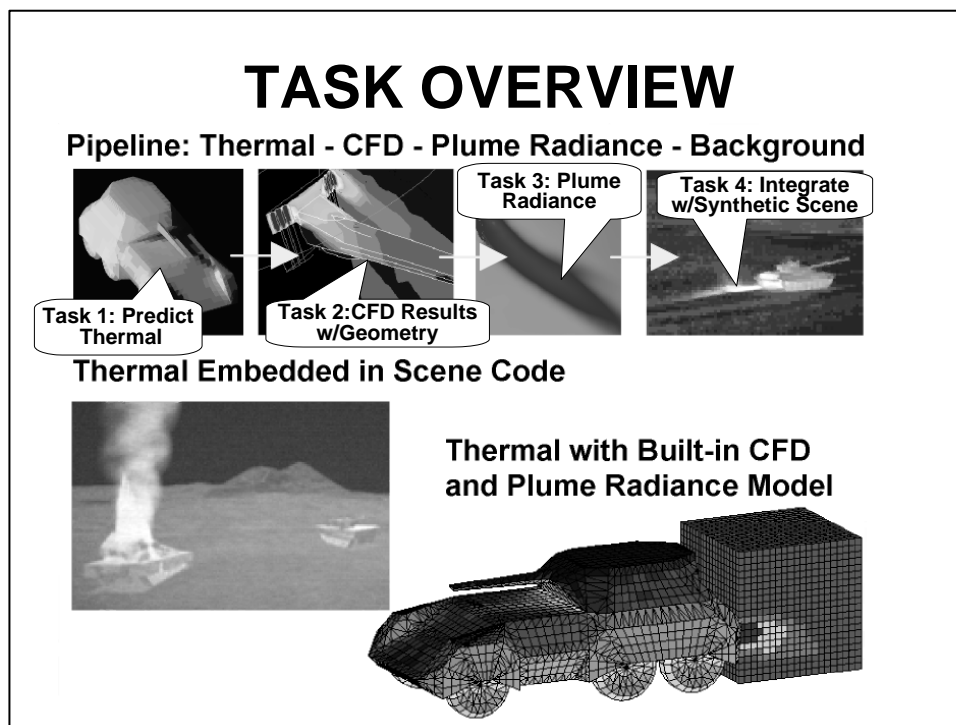


Figure 4 Another look at the task breakout

As a matter of practicality, we decided to try to embed the capabilities of predicting the exhaust in the target model as much as possible for a stand-alone capability for rapid prototyping and in parallel determine integration path to synthetic scene. The first three tasks can all be implement in the stand-alone MuSES code and distributed to the user community. The fourth task will then require us to have those effects interact with the synthetic code.

3.0 STATUS

Task 1 Predict surface temperature: Completed. There is ample literature on MuSES as a valid simulation tool for predicting vehicle temperatures⁴ so we are confident that task 1 is complete under the majority of circumstances. It is important to note that MuSES is under constant development and improvements and validation are ongoing for MuSES by many organizations in government and industry. Up until this latest release (version 7.0) many users wanting the engine predictive capabilities and flexibility of PRISM needed to use PRISM to generate the response curves and then input them into MuSES. With the release of version 7.0 and a generic engine model and with the release later this year of hook functions for users to write their own routines, this capability will be finally fully within MuSES. As far as this study is concerned however, the task is completed.

Task 2 Generate exhaust plume: Partially completed. This task involves automatically generating an exhaust plume. We must use caution when using the word "automatic". While some parameters can be set as default, this will never be a simple exercise (unless a model has already been set up and validated) and will require persons knowledgeable in this area. Today, engineers can predict the exhaust flow using a CFD code, which gives plume geometry and temperatures and flows. MuSES has links to commercial CFD codes such as FLUENT and STAR CD and we are working towards putting in the hooks to work with public domain NASA codes in order that organizations that cannot afford commercial CFD license fees will still be able to take advantage of this capability. Figure 5 shows an example of a notional plume prediction with the associated geometry for a Bradley. This geometry was created manually, however and was not generated automatically. Automating this process is the challenge and is underway.

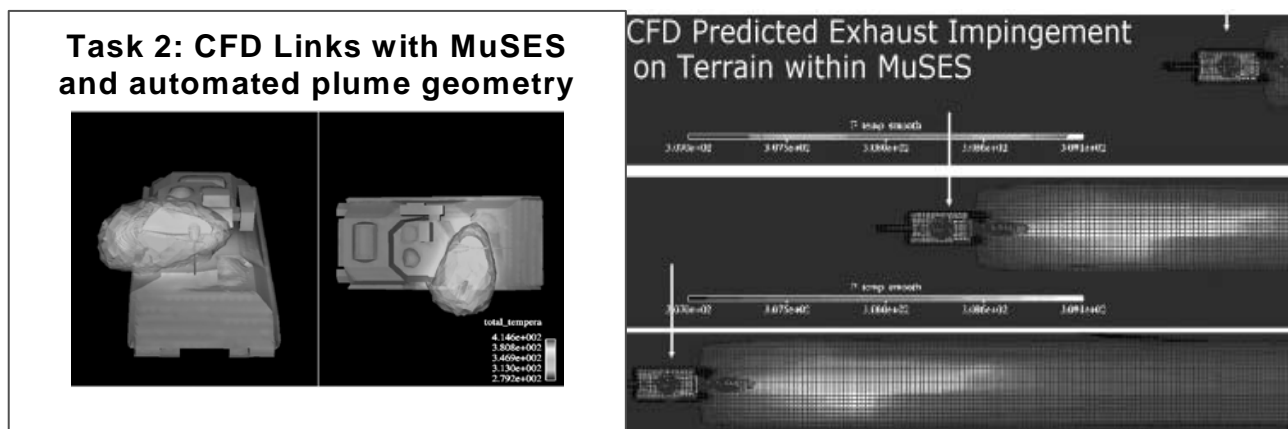


Figure 5 CFD results with automated plume geometry and example of exhaust impingement on a MuSES terrain

Figure 5 also shows scenes from an animation of an exhaust plume within MuSES heating a terrain as the vehicle moves over the terrain. Notice the ground heat and cool as the vehicle moves over the terrain. As a proof-of-concept, this part of the task has been completed, but was done manually. The goal is to automate this process and have it interact with a full synthetic scene renderer. Task 2 therefore is 50% completed.

Task 3 Render Plume with Radiation: In progress. As figure 3 shows, in addition to the convective effects that will be implemented via the CFD code, there are radiative effects as well. By using radiative codes such as SPURC and SIRRIM III, the proof-of-concept images in figure 6a and 6b were generated. Again, the images were generated with much user intervention (and in this case with spurious data to eliminate and classification issues). There are many challenges ahead to automate this process and have it link to the output from task 2.

Figure 6b has enough realism in the image to start begging the question--what is “good enough”. In this area as in most it will depend on the task. A helicopter designer looking to suppress the exhaust will be much more concerned about where the actual flow goes under certain circumstances than say a sensor designer looking at the helicopter 2 km away. Approximately 30% complete.

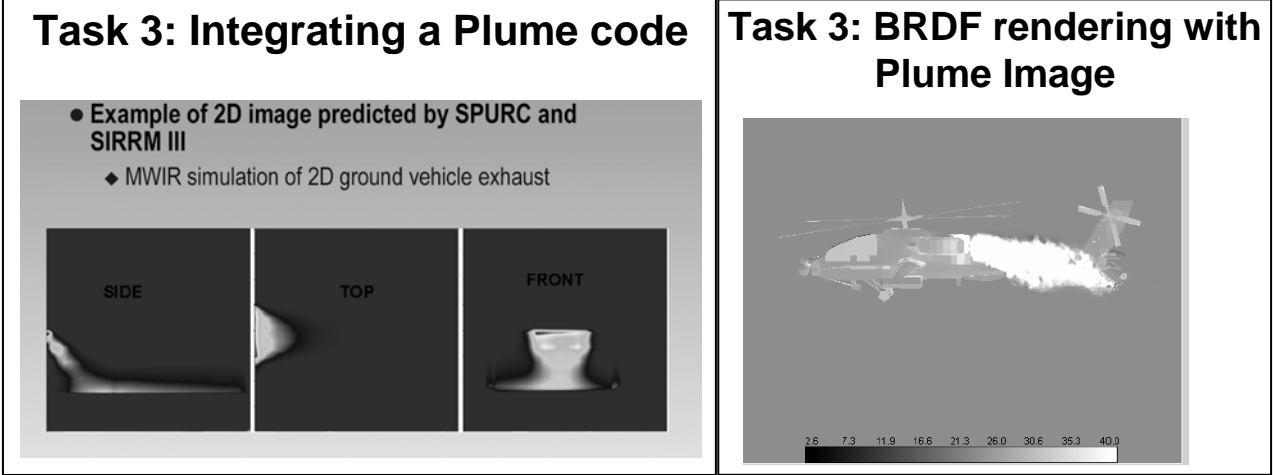


Figure 6 (a) Plume Radiance code image. (b) Example plume image rendered with BRDF

Task 4 Link to Synthetic scene: This next stage is in some ways the most challenging. Bringing several simulations together is always problematic. In this case, it is not simply a matter of needing a common architecture or method of passing information. In order to make the task more reasonable, we have broken the task into four levels of complexity as listed in table 1.

3.1 Defining the Levels of Interaction Between Vehicle and Terrain Models

These definitions are one of the bi-products of this study. It is our hope that these definitions can be refined within the community and be used as a vehicle for discussing the differences in simulations of this sort.

Vehicle-Terrain Interaction Level	What it stands for ...
Level 0	The synthetic scene reads in the target file and renders it. Temperatures on the target come from the target model. The synthetic scene renders appropriate radiation. No interaction between target and background. The user ensures time and weather correlation between target and scene
Level 1	No radiative interaction between target and scene, but target temperature and scene temperatures are time and weather correlated
Level 2	As Level 1, but target temperatures are affected by the scene
Level 3	As Level 2, but scene temperatures are affected by the target

Table 1. The Levels of Vehicle-Terrain Interaction.⁵

Level 0 is literally a cut and paste and then render. Most training simulators take this approach because it is the quickest and accomplishes much of what the simulation needs. The images in figure 7 show geometry that has been imported in the Cameo-Sim (CS) scene generator. Since the synthetic scene does radiative effects between the target and the terrain (not for heat transfer, but from a rendering perspective), you get these effects for free. The

consequences to this level are that the target temperatures will have been calculated using a thermal target simulation (TTS) thermal environment that would not necessarily be consistent with that defined within the Synthetic Scene Render (SSR) scene. Secondly, there is no time-of-day, orientation or altitude consistency. Thirdly, the background and target cannot thermally influence one another, whether through radiative or conductive means or through sky obscuration. Currently, this is the status for CS and PTN.

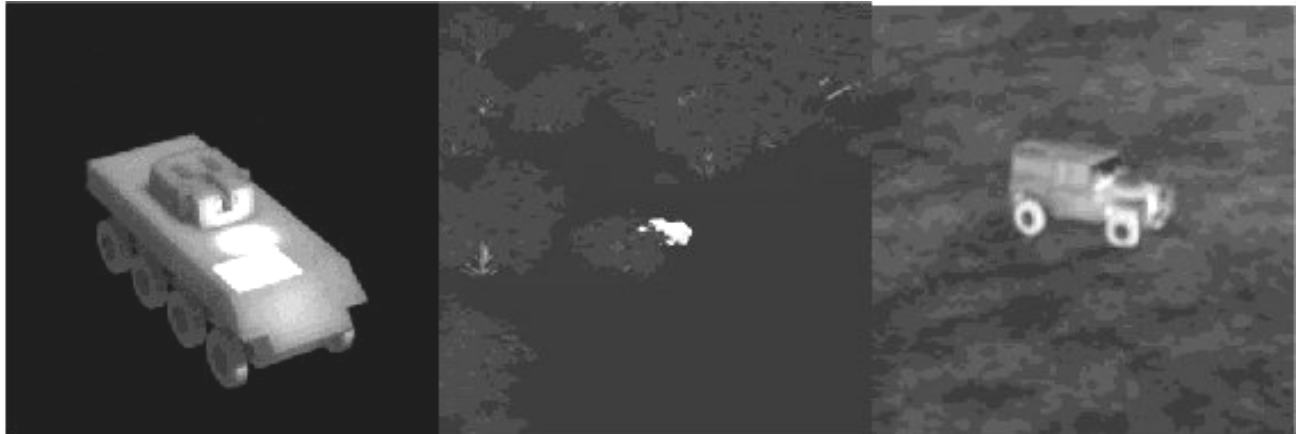


Figure 7 Level 0 type of imagery within Cameo-Sim. A future concept with no background. Same concept inserted into a scene. And a land rover in another scene.

Level 1: Synthetic Scene software interacts with target model software at level 1. Opens target file, synchronizes material properties (for proper rendering) and feeds back the weather scenario to the target model – drives the target model. No direct interaction between target and terrain. In this level, the TTS will be called by the SSR at rendering time once the target has been located within a scene and after atmospheric conditions have been assigned. Once a target is positioned within a scene, the thermal target simulation will, in principle, be able to predict the target's temperatures based on an atmosphere definition that has been matched to the assigned SSR atmospheric definition (eg. the correct time-of-day, orientation, altitude conditions, etc). The TTS can then correctly and with consistency solve the target's temperatures for a target located within that SSR scene. But similarly to Level 0, there will be no thermal interaction modeled between the target and background in this level. Status: This is currently in progress.

Level 2: Scene Influences Target: At this level, the thermal influence of the background on the target will also be considered. As in Level 1 though, there will be no thermal influence of the target on the background modeled. In this case, the temperature predictions for the background will remain within the SSR and independent of the target. SSR feeds the TTS appropriate surrogate terrain geometry local to the target and radiation & conduction interaction occurs on in target model only. Resulting radiative reflections will occur on terrain via the scene renderer. When the target is moving an infinite plane (geometryless) background of the appropriate type can be used. Shadowing of the target by trees, etc., is ignored. Status: Planned.

Level 3: Target Influences Scene: Same as level 2, but now plume impinges on surrogate terrain. These effects plus plume information are fed back to terrain model for final rendering. When the target is moving, the target interacts with a "scrolling" faceted terrain. Status: Planned. There are numerous complications involved with this task, not the least of which is that CS uses pixel based shadowing and MuSES uses polygon based shadowing. Trying to blend the predicted terrain between the two poses a challenge. A feasibility study has determined some possibilities. Status: Planned.

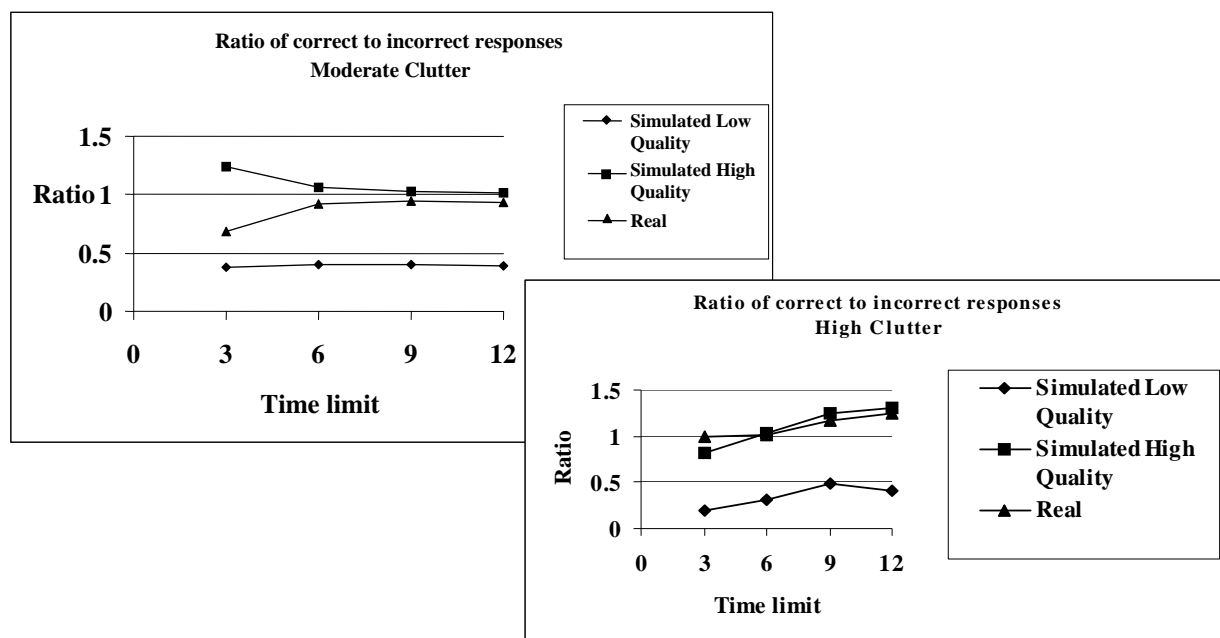


Figure 8 The results from the Time Limited Search Study

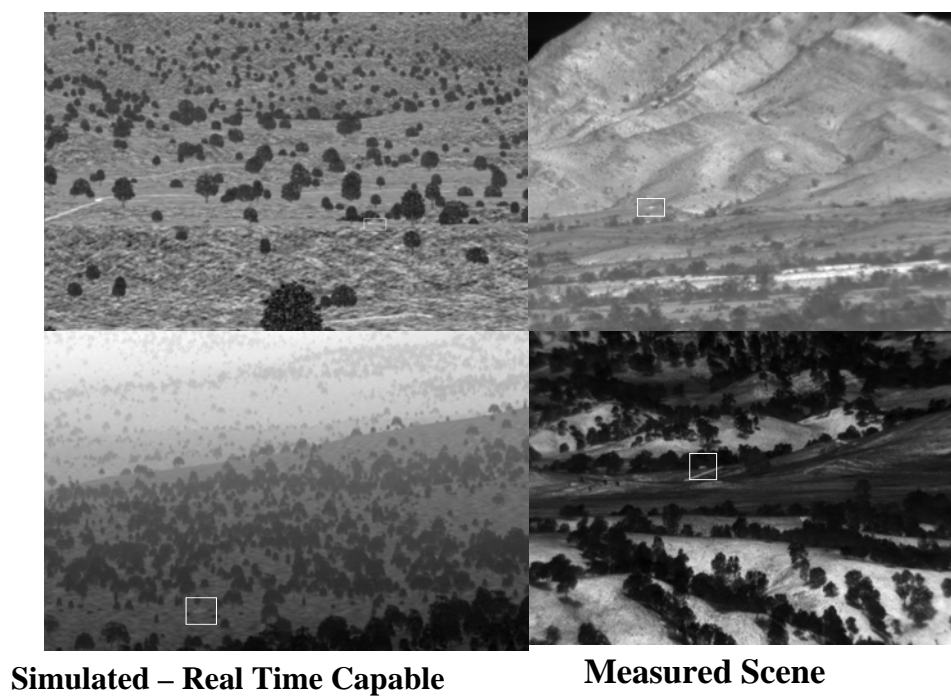


Figure 9 Some images from the Time Limited Search Study

3.2 How good is good enough?

As we develop this capability, there is a question that lingers in the background. We hinted at this in the plume discussion above. Before a simulation is developed, there need to be boundaries set--requirements specifications. We have asked that the model address certain phenomena, but how do we know when it is "good enough"? Some simulations do not account for these effects--are they really that important? The answer to this question is the same as any similar question asked of a simulation--it depends. It always depends on the task the model is asked to perform. The truth is, so much is unknown that the number of unanswered questions in the signature arena is substantial⁶. We cannot give exact specifications in this circumstance, but we can bound the problem along the way by using the tool itself. We will leverage tried and true methods for determining level of goodness in these situations, such as one in use at Night Vision Electronics Sensors Directorate at CECOM.

Edwards and Vollmerhausen et al⁷ conducted a time limited search study using measured imagery and wished to use simulated (synthetic) imagery (see figure 9) as well. They asked themselves--was the synthetic imagery up to the task? They used metrics specific to their task to determine whether their simulated scenes were appropriate to their experiment.

In this case (time limited search studies at tactical ranges) higher quality simulated scenes gave a good performance match to real images—particularly in higher clutter.



Figure 10. Measured image of T72 with exhaust plume impingement

We will design task oriented perception experiments based on measured scenes and determine tasked based metrics to use against synthetic scenes to determine if the target-terrain modeling we develop is necessary or sufficient.

For now, experience says we must include these effects to some degree to the best of our ability. Exhaust impingement on vehicle and ground can be a large LWIR cue depending on clutter and view angle – especially for ATRs--see the measured image in figure 10.

In addition, in making resolution and geometry representation choices, we must be aware of the effect described here by Curry

and Combs:

"The Stinger flight software, to enhance guidance accuracy against certain types of targets, has used edge-tracking algorithms extensively. This software feature can create considerable simulation accuracy problems for systems with low-resolution scene generation equipment. In triangle based systems such as the one that is being replaced with this system, the simulation seeker will tend to track on pointed objects such as the tips of triangles; on pixel based systems, the seeker will track the tip of an individual pixel or in the corner between two pixels. *To eliminate problems such as these, the scene generator must have a finer resolution than the missile seeker. The "movie generation" software must not only produce scenes with correct spatial and intensity attributes as related to the missile seeker, it must also properly convolve the entire scene to accurately match the seeker's optics and detector blur circle.*⁸ " [emphasis added]

3.3 Software Readiness Levels

The Army is striving to develop metrics of goodness for technology and software. These are referred to as "readiness levels". We have taken the general definitions of Software Readiness Levels and described them for this exercise. This can be found in table 2. As we develop this capability, we will use these definitions to describe our progress. Currently we sit at SRL 3.

SRL Definitions based on SRL guidance

Technology Readiness Level	Description
1. Basic principles observed and reported.	Lowest level of software readiness. Basic research begins to be translated into applied research and development. Examples might include a concept that can be implemented in software or analytic studies of an algorithm's basic properties.
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there is no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3. Analytical and experimental critical functions and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies to produce code that validates analytical predictions of separate software elements. Examples include software components are identified and partially integrated. Demonstrate that a vehicle can be taken from CAD into predictive scene without target/terrain interaction, simple atmosphere and sensor effects and basic metrics. Pieces exist and linkages can be done manually, but integration paths identified.
4. Component and/or breadboard validation in laboratory environment.	Basic software components are integrated to establish that they will work together. They are relatively primitive with regard to efficiency and reliability compared to the eventual system. While individual elements have a high level of validation, no validation effort on entire simulation has been performed.
5. Component and/or breadboard validation in relevant environment.	Reliability of software ensemble increases significantly. The basic software components are integrated with reasonably realistic supporting elements so that it can be tested in a simulated environment. Concepts are taken through the process and perception lab experiments are performed. The results are compared to perception lab experiments of comparable measured scenes. Path to link with MATREX is defined. Software releases are 'Alpha' versions and configuration control initiated. Verification, Validation and Accreditation (VV&A) initiated.
6. System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in software-demonstrated readiness. Examples include testing a prototype in a live/virtual experiment or in simulated operational environment. Algorithm run on processor or operational environment integrated with actual external entities. Software releases are 'Beta' versions and configuration controlled. Software support structure in development. VV&A in process.
7. System prototype demonstration in an operational environment.	Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in a command post or air/ground vehicle. An actual test site is simulated. Tests are run to determine input sensitivities and necessity of 2 nd and 3 rd order physics effects. MATREX integration path begins. Software support structure in place. Software releases are in distinct versions. Frequency and severity of software deficiency reports do not significantly degrade functionality or performance. VV&A completed.
8. Actual system completed and "flight qualified" through test and demonstration.	Software has been demonstrated to work in its final form and under expected conditions. The perception tests of actual field test sites and the ones generated synthetically have compared favorably. This TRL represents the end of system development. The tool can be used in stand-alone mode. The path to MATREX integration is completed. Software releases are production versions and configuration controlled, in a secure environment. Software deficiencies are rapidly resolved through support structure.

Table 2. The Software Readiness Levels of this capability

4.0 SUMMARY

This is a multi-organization effort based on extreme fidelity criteria specific to signature management and analysis. We have demonstrated success in identifying or developing the individual pieces required to simulate exhaust impingement effects using current CFD codes and plume codes. The challenges that lie ahead are in automating the process and the interface between the two models. We have developed what we hope to become a standard definition of levels of interaction between simulations of these sorts and we hope others will critique and/or adopt these definitions. We have completed what we have defined as a level 0 vehicle-terrain interaction in this effort and level 1 is in progress. We currently are at a Software Readiness Level of 3. There is a plan under development for validation and "level of detail required" analyses. And finally, lessons learned will be migrated to larger M&S efforts (MATREX). We will have a demonstration of an automated capability of level 0 schedule for this August, 2003. This program is currently unnamed but currently falls under the Army's new RDE Command.

5.0 ACKNOWLEDGEMENTS AND REFERENCES

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¹ Teresa Gonda, et al, "V & V of MuSES 6.0"; TARDEC Technical Report, Jan 2003.

² Cameo-Sim does have a real-time capability, however in this mode, it loses much of the capability that is the strength of Cameo-Sim; therefore it is not considered for this effort.

³ MATREX is a prime objective within RDE Command. Its goal is to connect different laboratories together in a distributed fashion. The simulation described in this paper is slated to become the "signature server" of MATREX.

⁴ Teresa Gonda, Alice Gerhardt, David Less, Al Curran, Pete Rynes, John S. Curlee, "V & V of MuSES 6.0 Status Report"; 13th Annual Ground Target Modeling and Validation Conference, Houghton, MI, August 2002.

⁵ C. Stroud, D. Filbee, et al, "Feasibility Study Report - An Investigation into the Interfacing of MuSES and Cameo-Sim", 001 a DRAFT, 14 April 2003

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⁷ Timothy C. Edwards, Richard H. Vollmerhausen, Jeremy Cohen, Tim Harris, "Recent Improvements in Modeling Time Limited Search", Aerosense Conference, SPIE Orlando 2002.

⁸ David M. Curry, Craig A. Combs, "Low Cost Target Scene Generation System for a Hardware-in-the-Loop Simulation of a Passive Infrared Guided Missile", US Army Aviation and Missile Command, Redstone Arsenal, AL 35898 e-mail: David.Curry@rdec.redstone.army.mil